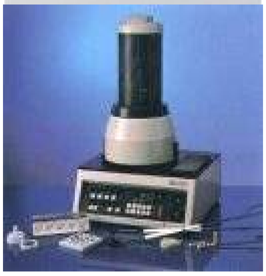
PHOENIX
DENTAL CASTINGS

Quick Guide to All Ceramic Processes

Part 1: Veneering Materials

All Ceramic Dental Restorations are generally characterised and described by the commercial name or the manufacturing process used to produce the coping or framework eg "Procera" "All Ceram", "Lava", "TechCeram" "InCeram" or "Empress". A Feldspatic porcelain (matched to the coefficient of linear expansion of the coping / framework) is then laid up by the ceramics technician to achieve the final clinical and aesthetic result.



We thought it might be interesting to provide an edited historical background to the development of dental porcelains before launching into the complexities of modern day ceramics copings and frameworks. Apparently it all began in China...

By the 10th century AD, ceramics technology in China was highly advanced. The white ceramic material they produced was so strong that vessels made from it needed a wall thickness of only 2-3 millimetres and were thus translucent. The internal structure was so homogeneous that a cup or dish if lightly struck would then ring like a bell. They had invented porcelain! The picture opposite shows a 16th Century Ming cup.

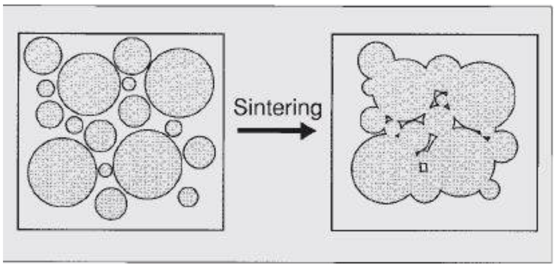
The earliest dental porcelains were first produced in France in the late 18th Century and used in the manufacture of denture teeth. They were mixtures of kaolin, feldspar and silica (quartz). Kaolin (china clay) is an hydrated aluminosilicate used to bind the other two components during construction and imparts opacity and strength. The silica (in the form of quartz), remains as a fine dispersion after firing adding translucency and strength, and feldspar, a mixture of sodium and potassium-aluminium silicates forming glass at around 1000degC. This formulation worked but provided a rather dull and unsatisfactory result. It was however considered superior to ivory which being highly absorbent and subject to severe staining became a biological nightmare!

By eliminating Kaolin (which caused opacity) from the mixture Elias Wildman (around1838) produced a dental porcelain with a degree of translucency and shades that fairly well matched those of natural teeth. Whilst solving one problem this unfortunately created another in that the material was substantially weakened and it took another 100 years before this problem was resolved. The milestones included the origination of the PJC concept by Beers in 1873, the introduction of the Richmond Crown in 1885 where porcelain was fused to a platinum post, and the introduction by Land in 1886 of the PJC backed by a platinum foil.

It was not until 1946 that the strength of porcelain was markedly increased by the introduction of calcined alumina and in 1949 when the Dentist's Supply Company of New York invented the process for vacuum-firing porcelain teeth. The use of a partial vacuum during vitrification resulted in porcelain teeth that were considerably more dense and less opaque.

Modern porcelain powders such as Shofu and Noritake are complex formulations of feldspar and silicates together with various metal oxides and binders. Certain oxides are introduced in order to produce the various shades eg oxides of iron act as a brown pigment, copper as a green pigment, titanium as a yellowish-brown pigment, and cobalt imparts a blue colour. Binders, consisting of starch and sugar, are present to help in the manipulation of the powders. You may have noticed that ceramics technicians are constantly licking their brushes when building crowns and it occurs to us that this might be due in part to the sugar content of the porcelain powders! In order to produce a dental crown the ceramic components are melted above their transition temperature, and the particles fuse together by liquid phase sintering, and then cooled. In this way the individual particles fuse together by sintering to produce a coherent solid.

Despite over 200 years of development the fundamental problem with dental porcelain remains; we can have strength but poor aesthetics or aesthetics but poor strength. As we really want good aesthetics the porcelain must therefore be supported by a core, coping or framework and if we want the best aesthetics that supporting material needs to be a non opaque relatively translucent material ie a ceramic having good mechanical properties.



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Quick Guide to All Ceramic Processes
Part 2: Coping and Framework Materials

Part one concluded that dental porcelain alone does not have sufficient strength to deal with the demands of restorative work and therefore needs to be supported by a suitable coping or framework capable of providing the underlying strength required. Anterior Porcelain Veneers are of course the primary exception here but we should bear in mind that the loadings are normally minimal compared to posterior restorations.

Three materials, Alumina, Zirconia and Leucite are in common use for ceramic copings and frameworks. They may be formed by various processes, (which will be dealt with in Part 3) and are then sintered, a process whereby the material is held at an elevated temperature which causes a molecular transformation. Following cooling the material then exhibits enhanced mechanical properties.

In general, ceramics materials have very high resistance to compressive loading but do not like being subjected to either bending or tensile loadings. For this reason connectors in ceramic bridge frameworks are designed with a relatively large cross sectional area in order to provide maximum resistance to bending.

Manufacturers data for the strength (usually termed flexural strength) of their materials is quoted in MPa "megapascals". 1 MPa is a pressure of approximately 10 Kg per square centimetre or in old money about 145 lbs/sq in. If we assume that the maximum biting force we normally generate is of the order of 20 Kg (44lbs) and the occlusal area over which this force is applied is around 1 square centimetre (assuming average molar contact area of 0.125 sq cm) then the average pressure generated will be: 20/1= 20kg/sqcm = 2 MPa (290 lbs/sqin). This of course assumes each molar carries an equal load. If all the occlusal load was carried by only four molars (two upper two lower) the pressure generated would then be around (20/0.25)=80kg/sqcm= 8 MPa (1160lbs/sqin) on each molar.

Figures quoted for the flexural strength of the various framework materials are in a range between 400 and 1200 MPa. These figures are substantially greater than the numbers shown above but we should bear in mind that these occlusal loads may be applied hundreds of times a day and that in the case of bridge frameworks resistance to flexing (or bending) is of prime importance in order to avoid failure due to repeated stresses caused by bending.

Alumina or Aluminium Oxide
Alumina is a chemical compound of aluminium and oxygen. Industrially, bauxite, the principal ore of aluminium is purified to aluminium oxide via the Bayer Process. The gems ruby and sapphire are mostly aluminium oxide, given their characteristic colours by trace impurities. The material is naturally white with a degree of transparency and good translucency. Once sintered, Alumina has sufficient strength for individual copings at any position in the mouth. Manufacturers figures for flexural strength are in the range 400 to 500 MPa. The strength of Alumina can be improved with the addition of minute glass particles by the InCeram process providing a flexural strength of around 700 Mpa.

Zirconia or Zirconium Dioxide
Zirconia is a white crystalline oxide of zirconium. This material can be generally termed "Industrial Diamond" due to its excellent mechanical properties. The processing (a number of processes are available) of zirconium involves the separation and removal of undesirable materials and impurities to create Zirconia. Zirconia is naturally white with virtually no natural transparency or translucency. Due to its superior mechanical properties Zirconia can be used for bridge frameworks, (including full arch restorations) at any position in the mouth. Manufacturers figures for flexural strength are in the range 800 to 1400 Mpa

Leucite or Potassium Aluminium Silicate
This material occurs at (among other places) Mt Vesuvius in Italy. Leucite comes from the Greek word for "white" in allusion to its typical colour . The material has a degree of natural transparency and good translucency. This Silicate forms the basis of the material used typically for pressable ceramics eg Empress. In its raw state, with suitable additions Leucite will flow under high temperatures and pressure and can therefore be forced into a mould in a process roughly similar to pressure die casting. The material has sufficient strength for individual copings in any position but is usually limited to frameworks for three unit anteriors only. Manufacturers figures for flexural strength are in the range 400 to 500 Mpa.

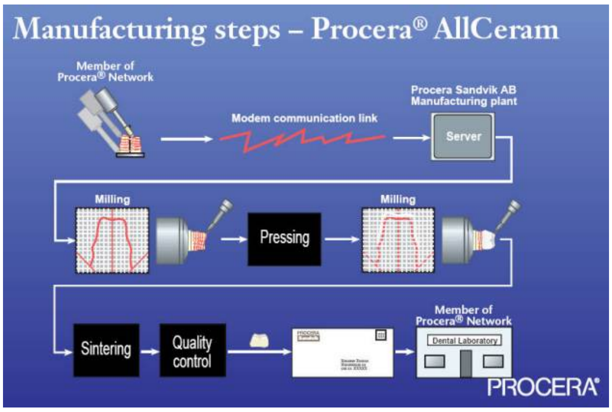
Quick Guide to All Ceramics

Part 3: Processes 1 of 3

Procera® AllCeram: Contact Scanning Computer Aided Design and Manufacture
This is our most popular all ceramic restoration for single crowns. Since its commercial introduction in 1994 more than five million Procera® restorations have been produced and installed. The impression is cast in a class IV stone for maximum accuracy and the die placed in a surface contact scanner as shown. Incidentally, the scanners are manufactured by a world famous British company called Renishaw.

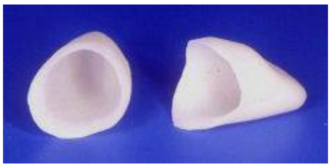
As the die rotates the probe moves vertically up the surface recording dimensional variations (to within ± 8ì m) from a known datum.

After scanning, the technician uses specially developed software to obtain best fit at the margins and the information is then stored in the computer as a 3dimensional table. This table is then E-mailed to Procera-Sandvik in Stockholm.



Using this information the Sandvik computers create a virtual replica of the die (the check die) which is used for final checking and a working die which includes allowances for expansion of the ceramics during processing and for cement in fitting.

Aluminium Oxide powder is then packed at very high density around the working die and pressed to form a first stage coping. This coping is then precision milled (0.4 and 0.6mm thicknesses available) on a specially developed CNC (computer numerically controlled) machine to produce the second stage coping which is then sintered at over 1000°C causing a molecular transformation and on cooling the material then exhibits enhanced mechanical properties. After inspection the coping is fitted to the check die to ensure correct fit and the coping is then sent back to us at the lab by airmail.

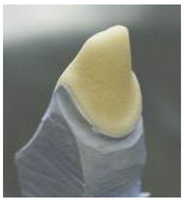


TECHCERAM: Combustion Powder Thermal Spray Process

Used to provide single copings the process involves feeding a specially formulated aluminium powder into a stream of burning gasses and "spraying" the resulting stream of molten particles onto a refractory die.

Firstly, the model is duplicated and a spray refractory model is cast. The base layer (coping) is manufactured by "Flame Spraying" specialist grade alumina powder onto the spray refractory model to a thickness of 0.5 mm.

The spray refractory is removed using glass bead blasting to leave the alumina shell together with over-spray which forms a support base during sintering. A specialist colouring glass is applied as a slurry. A choice of 10 shades are available to complement Vita™ Classical and 3D shade guides.



The base layer is then sintered at 1170°C for 60 min to yield a translucent, coloured, high strength coping. After further checks and processing the base layer is fitted on the die supplied and sent together with the original die to the Laboratory.

Quick Guide to All Ceramics Part 3: Processes 2 of 3

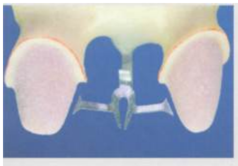
In-Ceram®: *Glass Infiltration Slip Cast Process*

This is a well proven system (introduced in 1989) for producing high-strength, oxide-ceramic substructures for single crowns as well as three-unit anterior and posterior bridges. In this system an Alumina slip (or slurry) is applied to the model dies and fired at 1120°C. The Aluminium Oxide (Al_2O_3) particles, are thus sintered, forming a bond at their contact points. The structure thereby obtained has a chalky consistency and is still easy to process.

Full strength is obtained after a further glass infiltration process whereby a special glass material is applied to the surface of the coping/framework and the item refired at 1100 °C. In this way the spaces between the Al_2O_3 particles is filled by the glass thus increasing the density and strength of the material.

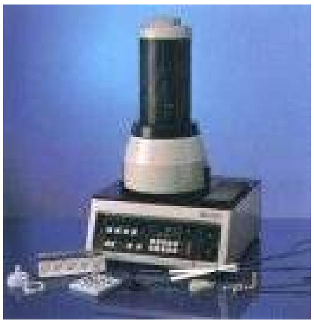
WolCeram®: *Electro Phoretic Ceramic Process with Non Contact Scanning*

This process uses electro-deposition to precisely apply a uniform thickness of InCeram alumina slip to the master die. An electronically conductive wax die spacer is applied to the die. Once loaded into the WolCeram machine, the die is scanned by laser for precise dimensional data. The die is then treated with an electrolyte solution to facilitate the EPC procedure and mechanically dipped into the InCeram slip material.



The electronically controlled surface charge created by the Wol-Ceram process attracts the InCeram slip particles to the die. The die is then briefly dried under a controlled heat source to stabilize the slip material.

Excess InCeram material is removed to expose the margin, additional trimming is performed and the coping is removed from the die. Sintering is performed followed by the application of the shaded glass material and a final firing. The molten glass infiltrates the coping resulting in a fine-grained structure with a glass matrix. By employing specially prepared formers this process can also produce bridge frameworks of up to three units.



IPS EMPRESS® 2: *Pressure Injected Ceramic System*

A wax up of the coping or bridge framework is produced sprued and invested in a similar way as for Porcelain Fused to Metal coping. The wax is then burned out and the refractory investment placed in a special ceramics press furnace. A shade coordinated ceramics ingot is then heated to its plastic state and pressed into the refractory mould creating a ceramic coping or framework. The ingot is pre-shrunk so the resulting ceramic coping fits accurately and is very strong. Veneering porcelain is then laid up on the pressing and fired to create the finished result.

Introduced in the mid 1980s' the first generation system (staining technique) quickly established a reputation for good aesthetics and set the standard for pressed ceramics systems.

The introduction of the second generation (layering technique) system in the mid 1990's enabled technicians to produce crowns and anterior bridges of excellent appearance, marred only by a tendency for the finished units to exhibit micro cracks. The problem was corrected but in the meantime the market had moved on to CADCAM produced copings and many laboratories had by then introduced alternative systems.

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CERCON, CEREC (from Sirona) and LAVA : Non Contact Scanning Computer Aided Design and Manufacture

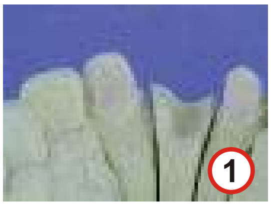

Fig 1

These systems all follow a basically similar process for the creation of an all ceramic crown or bridge restoration. Each relies on advanced scanning techniques in order to create a digital picture of the preparation. Opinions vary, depending on your view point, on the advantages of Contact Surface Scanning versus Non Contact Scanning. In the interests of time and space we will not go into detail here on the scanning techniques but will deal with this at a later date in Part 5 of this series.

The process may be summarised as follows:-

After a sectioned model (Fig 1) is produced it is optically scanned (Fig 2) and the restoration then "virtually" designed on a PC (Figs 3&4) using specially developed software. This is the computer aided design (CAD) part.

The software designs copings with a standardized wall thickness for crowns or abutments and selects suitable pontics from a range of predetermined basic designs. The shape of the copings and pontics can be further refined on screen by the use of tools from a pallet available in the software e.g. one available in the Lava system is called a "virtual wax-knife".

The preparation margins are also automatically detected and displayed by the system and lines of best fit achieved by the application of other software features.

The correct occlusal height for the coping or framework can also be determined here by taking the adjacent teeth and bite registration into account.

When finalised, the design in the form of a 3dimensional digital table is sent to a CNC (computer numerically controlled) milling machine (Fig 5) which machines a replica of the virtual coping or framework in a partially-sintered Zirconia or Alumina blank (Fig 6) . This is the computer aided manufacture (CAM) part. Any minor alterations or adjustments can be made by hand at this stage.

The unit is then placed in the furnace and sintered to achieve its finished density (Figs 7&8) . The process is carried out at temperatures in excess of 1000°C and takes up to 11 hours to complete.

The 4 unit anterior cantilever bridge and copings at fig 8 was actually produced in Zirconia by the Cercon Process. The unit is then passed to the specialist ceramics technician for application of the veneering materials (specially matched with the coefficient of thermal expansion of the framework) to create finished crowns or bridge (Fig 9) .

All pretty straightforward then. But perhaps few of us really appreciate the tremendous amount of R&D it took to create the software which drives these systems and the equipment used to create the finished product.

As much of the initial work was done in the aerospace industry in the manufacture of complex engine components in advanced metal and ceramics materials, this actually is "Rocket Science" technology!!

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Quick Guide to All Ceramic Processes
Part 4: Results

Matching Coefficients of Thermal Expansion.

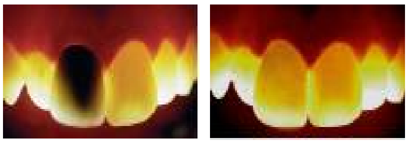
As well as variations in the strength and aesthetic characteristics there are also variations in the expansion coefficient (the amount a material expands or contracts per degree of temp change measured in micrometers per meter per deg C and abbreviated to "10^{-6}/°C") of the various ceramics used for copings and frameworks.

This means that the veneering porcelain must be selected in order to exactly match the base material thermal properties. Now with coefficients of linear expansion for Zirconia typically in the range 10 to 14 (10^{-6}/°C) one might be tempted to ask why such a small variation is important. The reason is that in order to obtain complete fusing of the veneer to the base material no differential movement at the adjacent material layers can occur after firing during the cooling phase. If the materials contract at different rates the interface between veneer and base will be weakened due to micro cracking. The result might then be failure of the veneer at some later date, typically when the patient takes a sip of hot tea or coffee or when enjoying a boiled sweet!

Clinical Results.

It is difficult to provide completely up to date information here as a number of trials with newly available systems are ongoing. What we can say is that based on published results there has been a substantial improvement in the success rate with all ceramics during the 1990s. For example information on InCeram published in the late 1980s gave an overall success rate of around 85% compared to data published by Noble Biocare on Procera in 1996 where the success rate was around 95%. Based on feedback from clients over the past two years the success rate appears to be in the high nineties and improving.

The main reasons for this improvement are most likely:-
Greater appreciation of indications and prep techniques by practitioners
Improvements in materials and processing methods
Improvements in technician training for all ceramics work



Aesthetics

As we implied in Part 1 the main reason for the introduction and development of all ceramics restorations is aesthetics. Whilst dental technicians are capable of producing excellent porcelain bonded to metal crowns it is very difficult to create a completely lifelike restoration on an opaque metal base. The pictures of these back lit upper right centrals *(top right)* clearly illustrates this.

Clearly all ceramics restorations are leading the way in terms of aesthetics and with the introduction of Zirconia we are now able to provide all ceramics cantilevered anterior restorations as shown here left as well as fixed /fixed posterior bridges shown right.

For best results we recommend using the Shade Ladder System whereby you will be able to provide us with a detailed aesthetic specification which should result in a perfect match every time.

If you would like information on the Shade Ladder system
call Rachel on 01392 444456

And finally thanks to **Nobel Biocare, TTC Ltd, Noritake, Shofu, Cercon, Sirona, 3M, Ivoclar, Renishaw** and **Dr Gustav Eriksson** for providing material used in this series